USAFSAM-TP-90-22

REFURBISHING AV-8 ON-BOARD OXYGEN GENERATION SYSTEM BEDS

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December 1990

Interim Report for Period May 1990 - August 1990

USAF SCHOOL OF AEROSPACE MEDICINE
Human Systems Division (AFSC)
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NOTICES

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) USAFSAM-TP-90-22	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION USAF School of Aerospace Medicine 6b OFFICE SYMBOL (If applicable) USAFSAM/VNL	7a NAME OF MONITORING ORGANIZATION
6c ADDRESS (City, State, and ZIP Code) Human Systems Division (AFSC) Brooks AFB TX 78235-5301	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING/SPONSORING ORGANIZATION USAF School of Aerospace Medicine 8b OFFICE SYMBOL (If applicable) USAFSAM/VNL	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Human Systems Division (AFSC) Brooks AFB TX 78235-5301	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: 62202F PROJECT NO: 7930 TASK NO: 11 WORK UNIT ACCESSION NO: 24

11 TITLE (Include Security Classification)

Refurbishing AV-8 On-Board Oxygen Generation System Beds

12 PERSONAL AUTHOR(S)
Ikels, Kenneth G., and Shakocius, Aaron M.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Interim	FROM 90/05 TO 90/08	1990, December	27

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
11	07		Oxygen Separation, Zeolite Packed Beds
23	05		

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The Crew Systems Branch, Crew Technology Division, USAF School of Aerospace Medicine has carefully prepared specific procedures and instructions to provide users of the AV-8 "HARRIER" On-Board Oxygen Generation System (OBOGS) with detailed information and requirements on refurbishing OBOGS beds.

Included in the instructions on disassembling, repacking, and assembling the OBOGS beds, are specific procedures for determining the activity and, if necessary, activating the molecular sieve before the beds are repacked. In addition, technics and procedures are detailed for testing the repacked beds prior to reassembly of the concentrator to ensure efficient air separation.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT	21 ABSTRACT SECURITY CLASSIFICATION	
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	Unclassified	
22a NAME OF RESPONSIBLE INDIVIDUAL Kenneth G. Ikels	22b TELEPHONE (Include Area Code) (512) 536-3361	22c OFFICE SYMBOL USAFSAM/VNL

DD Form 1473, JUN 86 *Previous editions are obsolete*

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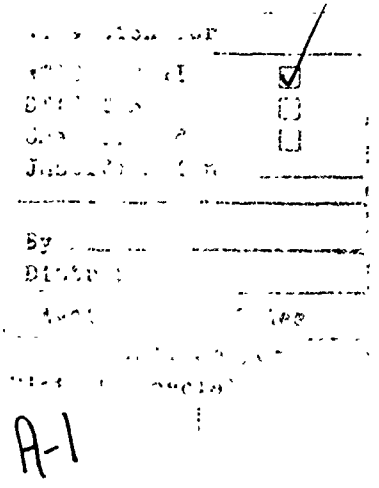

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REFURBISHING AV-8 ON-BOARD OXYGEN GENERATION SYSTEM BEDS

INTRODUCTION

Repacking On-Board Oxygen Generation System (OBOGS) beds requires a modicum of care and effort to be performed correctly. Five items should be carefully considered when repacking the concentrator beds:

1. Use activated molecular sieve whose water content is less than 1%.
2. Ensure that the internal surfaces of the bed are free of contaminants and dust.
3. Use the "snowstorm" technique.
4. Ensure part alignment.
5. Assure an unobstructed inlet port flow path.

Bulk Molecular Sieve

The bulk molecular sieve (5A-MG) used to repack the concentrator beds should be tested for water content. A value less than 1% will ensure proper oxygen concentration in the outlet gas. Should the bulk sieve show a water content greater than 1%, it is imperative that the sieve be activated prior to use. For detailed information on activating the sieve, please refer to the section on activating bulk molecular sieve.

Contaminant Removal

After the bed has been disassembled, all the parts should be inspected for dust or other contaminants. Under normal operating conditions, minute quantities of dust can be generated in the beds. Therefore, this dust and any other contaminants should be removed before repacking the beds.

"Snowstorm" Technique

When refilling the bed with molecular sieve, the best packing method available is the "snowstorm" technique, which separates the sieve particles and allows them to pack to a minimum volume, thus eliminating possibility of damaging the bed by continuous tapping. When filling the bed with sieve, the outer annulus should be filled first, using the inner annulus centering tool to stabilize the inner annulus. Filling the bed in this manner will facilitate the refitting of the upper retaining plate.

Part Alignment

Before a bed is disassembled, it is imperative that the original position of three key parts be marked for future reference. The position of the upper retaining plate and base plate in relation to the outer annulus must be the same after reassembly of the bed in order for the bed gas inlet and outlet ports to be properly aligned with the concentrator frame.

Unobstructed Flow Path

When reassembling a bed, the possibility exists for one of the outer annulus retaining screen springs to be placed in such a position that it obstructs the flow path of the inlet/outlet port of the bed (1/2" diameter hole in the upper retaining plate). If obstruction occurs, the overall performance of the bed, and thus the concentrator, may be affected. Therefore, care must be taken to assure an unobstructed gas flow path into the bed so that the concentrator may perform at an optimum level.

ACTIVATING BULK MOLECULAR SIEVE

When bulk molecular sieves are purchased from vendors, generally the composition of the sieve with respect to binder content and water content can vary. For the best results, the molecular sieve should contain less than 1% water. Should the water content exceed the 1% level, it becomes necessary to reactivate the sieve.

The two techniques that are widely used for activating the sieve are heating under vacuum and heating with a gas purge.

Heating the sieve under vacuum is probably the technique of choice; however, the quantities of sieve needed to repack an OBOGS concentrator require a rather large container that can maintain a vacuum (less than 1 Torr) while being heated to 350 °C (662 °F) for a period of at least 8 h. Vacuum seals on large containers can be a problem particularly when heated and reheated to 350 °C, and it becomes increasingly difficult to maintain proper vacuum due to vacuum seal deterioration. If a reliable container of this type were available, we would recommend activation of the sieve by vacuum heating at 350 °C for an 8-h period. When cooled to room temperature, dry air or nitrogen is introduced into the container to bring the pressure inside the container to ambient pressure.

A possibly more manageable technique to activate large quantities of sieve is heating and purging with nitrogen gas. With this technique, leaks in the container are not critical since all leaks will be outboard, resulting from the slightly higher pressure from the purge gas. A container capable of heating 12 kg of sieve to 350 °C should have a purge flow of nitrogen between 2 and 4 L/minute. Following 8 h of heating, the system can be cooled to room temperature while still being purged with nitrogen.

The activated sieve should be tested to ensure that the water content is less than 1% to ensure proper oxygen concentration when used to repack the OBOGS beds.

BED REPACKING PROCEDURE

Considering the five important items in refurbishing the OBOGS beds, the repacking procedure detailed next is probably the most important. Not following these steps precisely could lead to difficulty in reassembly of the concentrator as well as poor oxygen output from the system.

The "snowstorm" technique used in this procedure has been used in our Crew Systems laboratory for a number of years. We have found this technique to be the best and most reproducible way to pack the OBOGS beds.

Refer to Figures 1 and 2 for identification of all parts.

1. Once the beds have been removed from the concentrator, carefully mark the upper retaining plate and base plate so that their position in relation to the outer annulus can be restored.
2. Remove the upper retaining plate and the outer annulus retaining screen.
3. Place a piece of tape on the inside of the outer annulus to mark the fill level of the molecular sieve, then discard the old sieve.
4. Remove the inner annulus retaining screen, similarly mark the fill level of the molecular sieve in the inner annulus, and discard the old sieve.
5. Remove the inner and outer annuli from the base plate.
6. Remove the lower retaining screen.
7. Now that the bed is completely disassembled, assure that all of the bed parts are clean and free from dust and other contaminants.
8. Install the lower retaining screen onto the retaining post, foam side up, and place it so that the screen positioning pegs come through the screen positioning holes.
9. Slide the outer annulus over the base plate. Make sure that the lower rim of the outer annulus is completely flush against the base plate lip, and that the marks on the outer annulus and base plate are precisely aligned. Then, place the inner annulus over the screen positioning pegs.
10. Carefully weigh all parts of the bed together (including all parts of the bed as if it were completely assembled, i.e., upper retaining plate, retaining screens, springs, washers, nuts, etc.). This weight will be the bed weight before adding sieve.
11. Install the inner annulus centering tool to position the inner annulus, then fill the outer annulus using the "snowstorm" technique, and remove the tape marker.
12. Remove the inner annulus centering tool, fill the inner annulus using the "snowstorm" technique, and remove the tape marker.
13. Install the inner annulus retaining screen, retainer spring, washer, and nut.
14. Install the outer annulus retaining screen, and position it in such a way that the inlet port of the bed will not be obstructed by any of the outer annulus retaining screen springs.

15. Install the upper retaining plate, making sure that the marks on the upper retaining plate and outer annulus are precisely aligned, and install the washer and nut.
16. Weigh the assembled bed. The weight of the molecular sieve contained within the bed may be obtained by subtracting the weight of the bed parts before adding sieve from the weight just obtained. The weight of the sieve in the bed should be within 2,450 to 2,550 g.
17. Reassemble the OBOGS unit.
18. Retest the concentrator at specified Naval Air Development Center (NADC) inlet pressures and product flows to ensure proper oxygen concentration production.

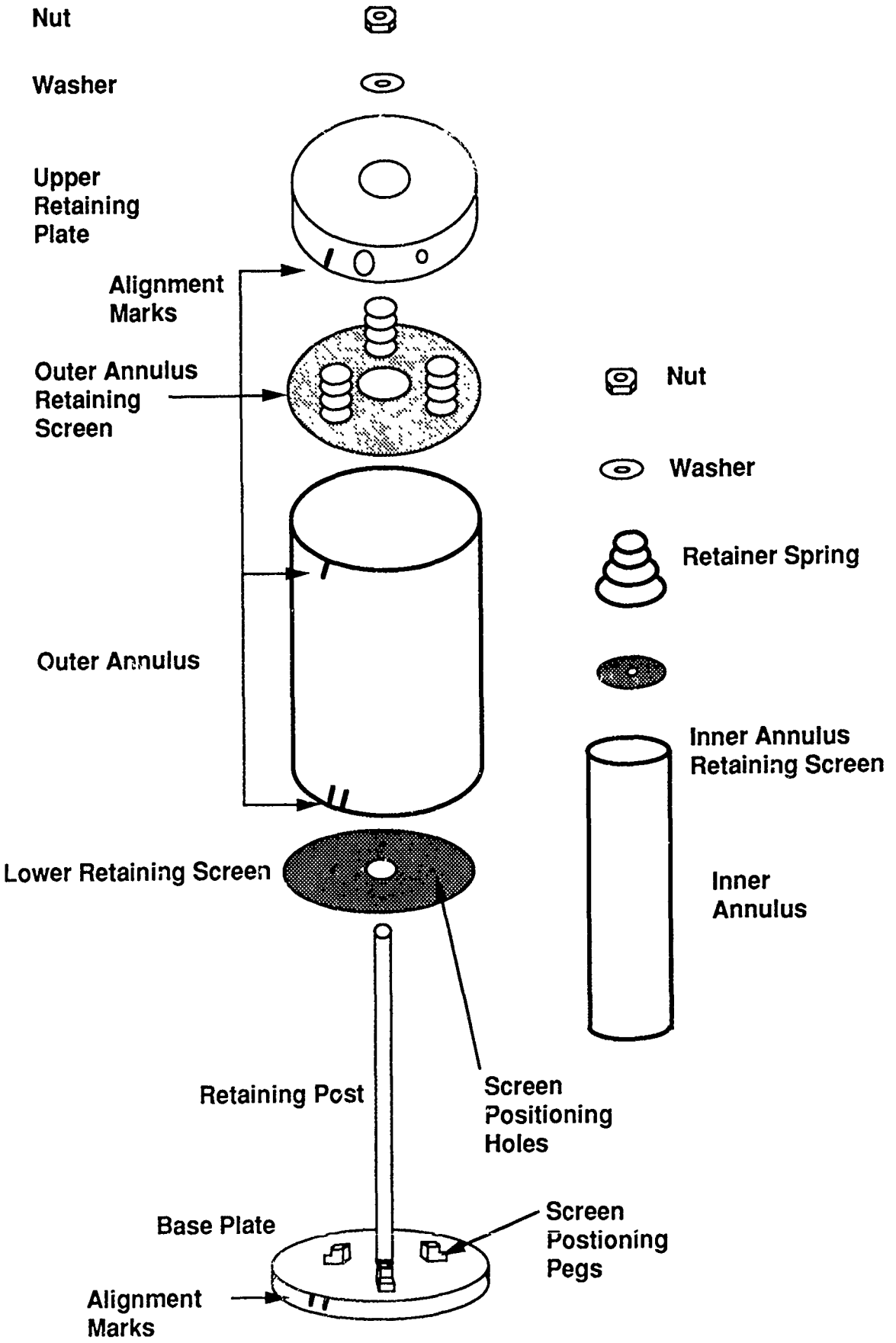

Figure 1. Detail of bed parts.

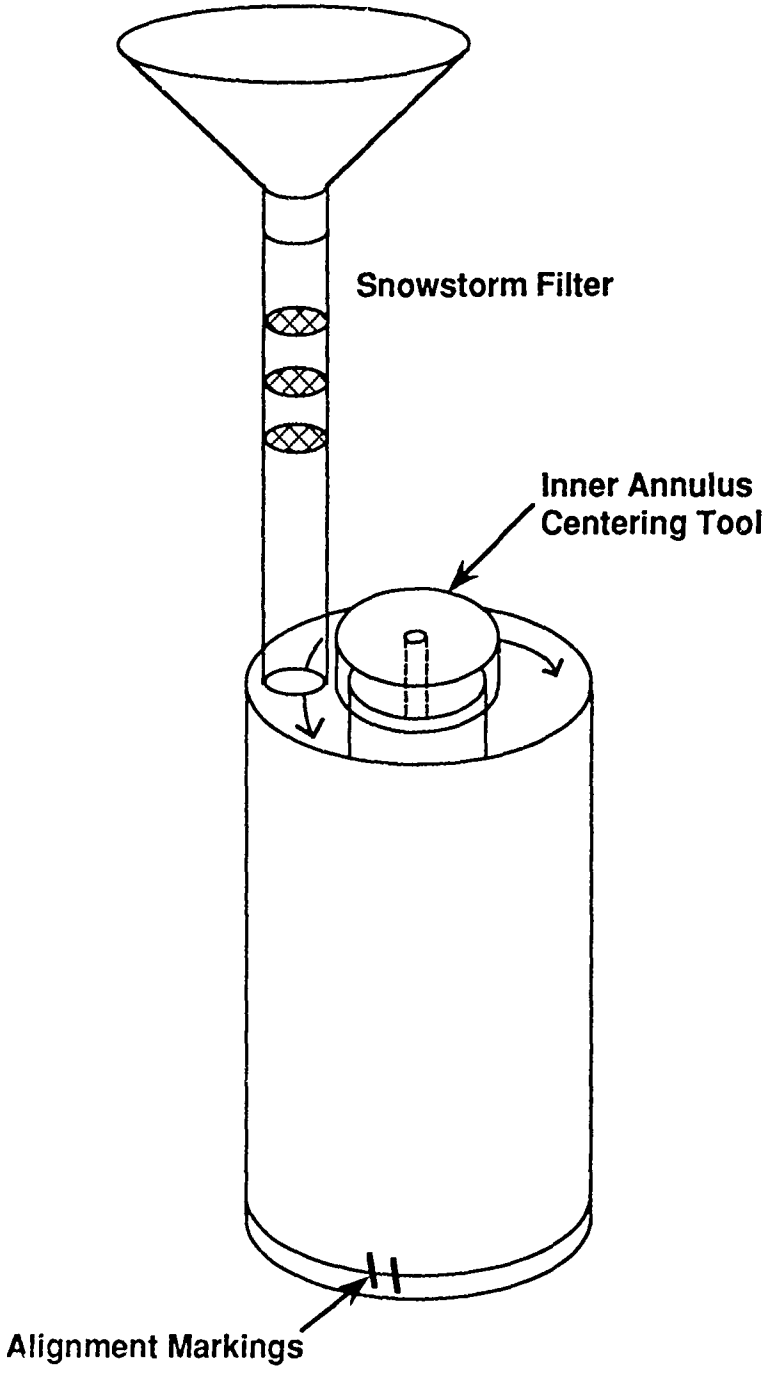

Figure 2. Detail of Snowstorm technique while filling the outer annulus.

WASHOUT PROCEDURE

The OBOGS utilizes a pressure swing adsorption (PSA) process, which is a dynamic process, to generate oxygen enriched gas. The washout technique performed on a molecular sieve filled bed using both nitrogen and oxygen is also a dynamic process and, therefore, the best assessment of the condition of an OBOGS bed. In addition, the washout technique provides an excellent quality control procedure to ensure that the beds of the OBOGS have been properly packed with active molecular sieve. Differences in washout times of the beds could indicate nonuniform packing. The washout procedures as detailed below were developed in our laboratory during the early 1980's for the express purpose of determining the dynamic characteristics of a molecular sieve filled bed. For a more detailed description of the washout technique, see the report titled, "The Effects of Moisture On Molecular Sieve Oxygen Concentrators" by K.G. Ikels and C.F. Theis, Aviation Space and Environmental Medicine, January 1985.

Washout data for two sets of molecular sieve oxygen concentrator beds has been provided at the end of this report (Appendix). The first set of beds was repacked by the NADC, while the second set of beds was repacked by the concentrator manufacturer, Litton Instruments and Life Support, Davenport, Iowa 52808-4508.

Experimental Setup

1. The inlet and outlet ports of the bed must be easily accessible; therefore, the bed must be removed from the concentrator before the washout procedure can be performed.
2. Seal the holes in the bottom of the bed with some kind of tape or plug. No hard seal is necessary as the bed will be at or near ambient pressure during the procedure.
3. Install a Swagelok connection tube, shown in Figure 3, into both the inlet and outlet port of the bed. (The short end of the connection tube may be either 5/8" or 5/16" O.D. The 5/8" tube inserts into the larger inlet port and has a 1/2" Swagelok nut on the opposite end, and the 5/16" tube inserts into the smaller outlet port and has a 1/4" Swagelok nut on the opposite end.)
4. Connect the bed to the experimental apparatus as illustrated in Figure 4.

5. Set the flow from the nitrogen and oxygen bottles at 414 kPa (60 psig) and 30 L/minute as detailed in the publication. To accomplish this procedure, first set the two-way valve so that oxygen is flowing into the bed. The needle valve on the oxygen bottle should be completely open. Next, allow the bed to saturate with oxygen, then set the control valve so that the rotameter reads 30 L/minute (the control valve is the valve situated between the pressure gauge and the bed). The pressure gauge should read 414 kPa (60 psig). Finally, switch the two-way valve to the nitrogen bottle, and set the pressure at 414 kPa (60 psig).
6. As shown in Figure 4, the oxygen concentration is measured downstream of the bed and can be determined by a polarographic type oxygen sensor (i.e., Beckman OM-11) or by a mass spectrometer type gas analyzer (i.e., Perkin-Elmer medical gas analyzer).

Results

1. Switch the two-way valve back to oxygen and allow the bed to saturate with oxygen. (A bed is assumed to be saturated when the gas reading down stream of the bed reads 100%.) After the bed is saturated with oxygen, switch back to nitrogen, and record the time it takes for the oxygen concentration in the bed to drop to 37%. Next, allow the bed to saturate with nitrogen, switch back to oxygen, and record the time it takes for the oxygen concentration to reach 63%. Prime emphasis will be on the $O_2 \rightarrow N_2$ washout curve.
2. Subtract 7 s from the washout times before comparing your results to Figure 5. Seven seconds is the time required to washout the void volume of the bed and is specific for the AV-8 bed. Seven seconds is a valid quantity to subtract from the original washout times as long as the bed geometry does not change and the quantity of sieve in the bed is approximately 2,500 g (plus 100 or minus 25 g).
3. The minimum washout time should be 38 s (after subtracting 7 s for the void volume washout time) for a freshly packed bed. When compared to Figure 5, 38 s would equate to a ratio (active to deactivated molecular sieve) of approximately 90%.

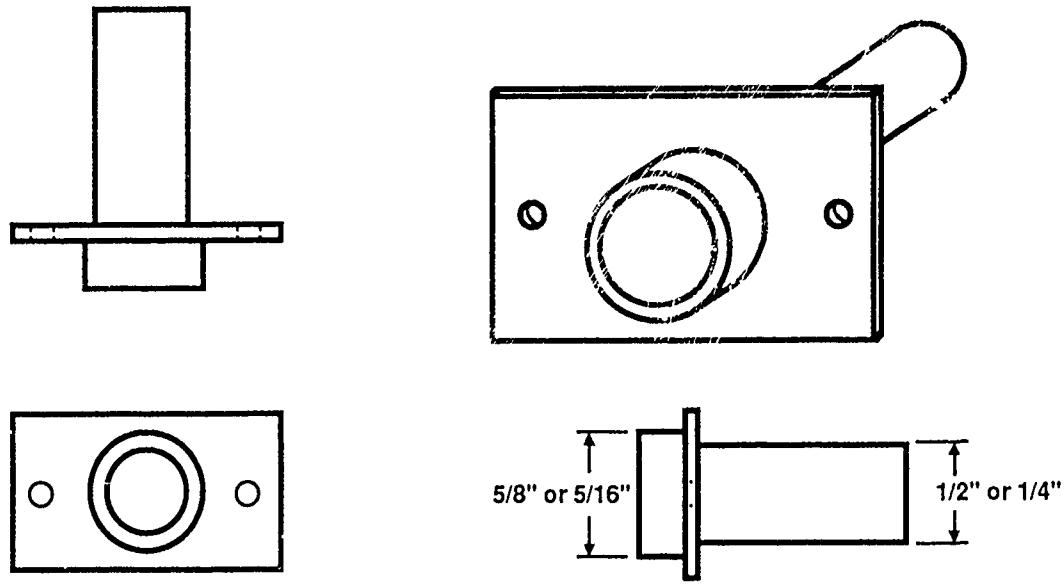

Figure 3. Swagelok connection tube. (Not to scale)

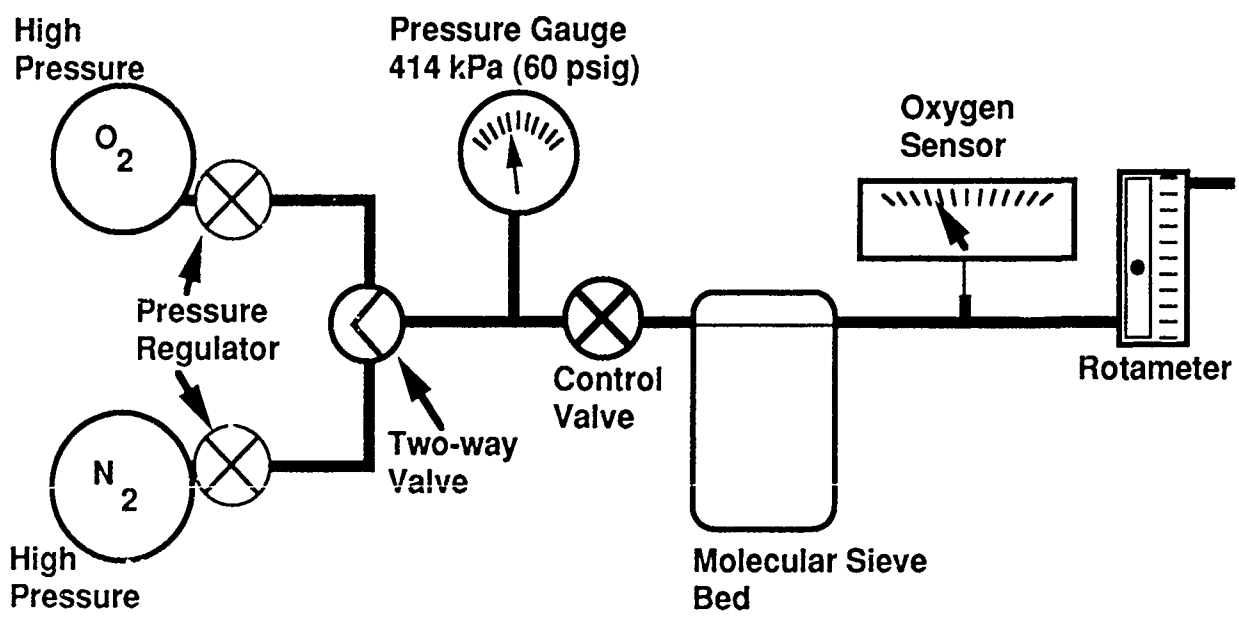

Figure 4. Experimental apparatus for molecular sieve bed washout studies.

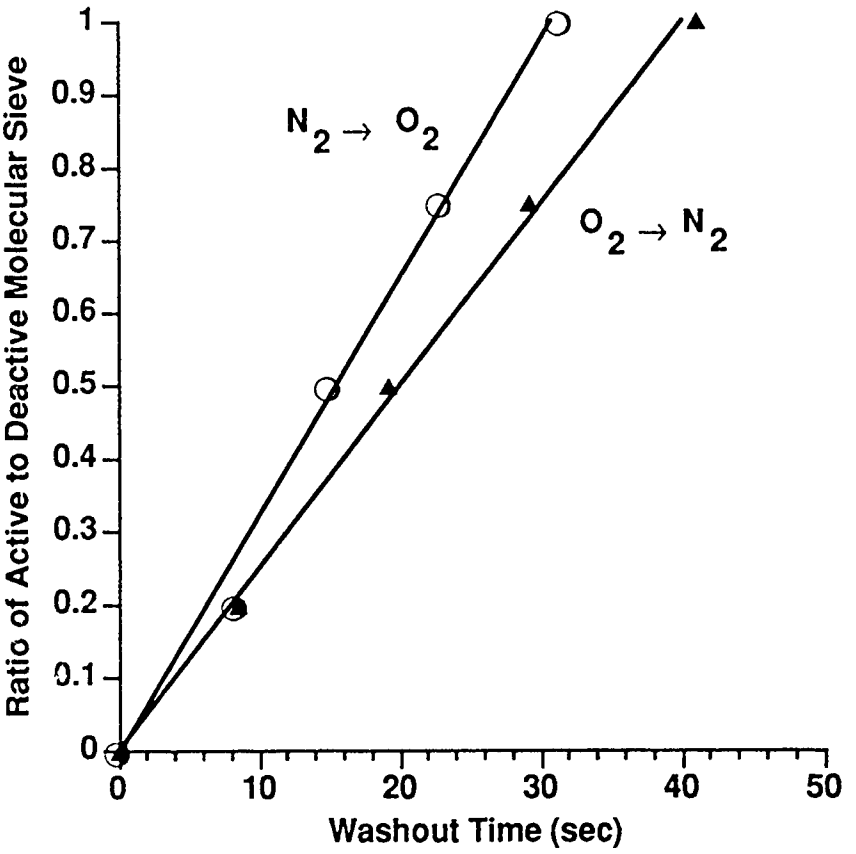

Figure 5. Graph of washout time vs. activity.

ADSORPTIVE CAPACITY BED TESTER

An alternative method for determining the condition of a molecular sieve bed is to measure the adsorptive capacity of a gas on the molecular sieve at equilibrium. A procedure of this type has been developed by G. W. Miller and is detailed in U. S. Patent # 4,916,630, 10 Apr 1990. In this procedure, a gas, generally nitrogen at a known pressure and temperature, is allowed to adsorb on a known weight of molecular sieve, resulting in an increased total weight. This increased weight due to the adsorption of the gas is then correlated to the isotherm of that gas on pure molecular sieve. From this information, capacity of the sieve can be determined. When comparing the weight of gas adsorbed to that adsorbed on an equivalent weight of activated sieve, one can arrive at an activity ratio. In a similar manner, the water content of the sieve can be determined.

This technique utilizes a user friendly computer program which guides the user through each step of the procedure, and requests the user to input data at various points of the process. The program then uses this data to calculate the activity and water content of the molecular sieve.

Although this method of testing molecular sieve is not a dynamic method, as is the washout technique, it is a simple and reliable method for determining a molecular sieve bed's adsorptive capacity and water content.

Static adsorption activity data for two sets of molecular sieve oxygen concentrator beds has been provided at the end of this report. The first set of beds was repacked by the NADC, while the second set of beds was repacked by the manufacturer, Litton Instruments and Life Support, Davenport, Iowa 52808-4508.

GRAVIMETRIC ANALYSIS OF MOLECULAR SIEVE FOR PERCENT WEIGHT WATER

The gravimetric analysis technique is a relatively simple and straightforward laboratory method. In this procedure, the results of the analysis provide important data concerning the water content of the sieve. Gravimetric analysis of molecular sieve for percent weight water is a means for determining the water content of a sample of molecular sieve. Refer to Figures 6 and 7 for identification of the various

apparatus used in this procedure. The following materials are needed to perform this analysis:

1. Aluminum heating block with Watlow heating rods and temperature thermocouple installed.
2. Heating block stand.
3. Variac.
4. Temperature monitor readout.
5. Vacuum pump with shut-off valve.
6. Tygon tubing manifold.
7. Supply of glass ampules (Available in the American Scientific Products catalog as KIMAX-51 Colorbreak Trimmed Stem Ampules, cat # A1900-2, mfr # 12012L2).
8. Supply of glass wool (Available in the American Scientific Products catalog as Pyrex Brand Fiber Glass Wool, cat # G6010).
9. Scale with an accuracy of at least 0.001 g.
10. At least four small numbered jars that can hold a single glass ampule each.

NOTE: The glass wool and ampules should be stored in a desiccator so that they remain as free from moisture as possible.

The following steps are involved in gravimetric analysis of molecular sieve for percent weight water:

1. Obtain an approximately 20 g sample of molecular sieve that is representative of the stock molecular sieve. Care must be taken so that the sample is not unnecessarily exposed to atmospheric moisture.
2. Obtain at least four clean glass ampules and place one ampule into each of the numbered jars. It is best to avoid handling the ampules with bare hands which can cause the weight of the ampules to be inconsistent throughout the analysis. It is advisable to handle the ampules with tweezers or while wearing surgical gloves.
3. Weigh and record the empty weight of each ampule, storing each ampule in its respective numbered jar.
4. Using a small funnel, pour a small amount of sieve into an ampule, filling it up to about one-quarter inch below the narrowest part of the ampule neck.

5. Weigh and record the ampule and sieve.
6. Repeat steps 4 and 5 for each ampule.
7. Insert a very small portion of glass wool into the neck of the ampule.
8. Repeat steps 7 and 8 for each ampule.
9. Place each ampule in numbered order into the aluminum heating block starting from the left.
10. Place one tube of the Tygon tubing manifold over the end of each glass ampule.
11. Pinch off any of the remaining tubes on the manifold so that the manifold is completely sealed.
12. Turn on the vacuum pump with the shut-off valve closed.
13. **VERY SLOWLY** open the shut-off valve and allow the ampules to evacuate.
14. Set the variac so that the temperature of the aluminum heating block stabilizes at 350 °C.
15. Heat and evacuate the ampules at 350 °C for a minimum of 4 h.
16. When the heating period is complete, turn off the variac, but leave the vacuum pump running, and allow the aluminum heating block to cool to room temperature.
17. Close the shut-off valve, turn off the vacuum pump, and **VERY SLOWLY** release the vacuum within the Tygon tubing manifold.

    NOTE: When releasing the vacuum within the manifold, the gas entering the manifold should be as dry as possible. This function can be accomplished either by using dry nitrogen or by using air filtered through an adsorbent.
18. Carefully remove a vacuum tube from the neck of an ampule and place the ampule in its respective numbered jar. Again, it is best to handle the ampules with tweezers or gloved hands. Repeat this step for each ampule.
19. Carefully remove the glass wool plug from an ampule.
20. Weigh and record the weight of the ampule and sieve.
21. Repeat steps 20 and 21 for each ampule.
22. The weight of the molecular sieve in each ampule before heating is given by:

$$MS_B = AS_B - A_B$$

where

MS_B = weight of sieve before heating
AS_B = weight of ampule and sieve before heating
A_B = weight of ampule before heating

23. The weight of the molecular sieve in each ampule after heating is given by:

$$MS_A = AS_A - A_B$$

where

MS_A = weight of sieve after heating
AS_A = weight of ampule and sieve after heating
A_B = weight of ampule before heating

24. The percent wt. water is obtained from the change in the weight of the molecular sieve after heating and is given by:

$$\%W_{H_2O} = \left[\frac{MS_B - MS_A}{MS_B}\right] * 100$$

where

$\%W_{H_2O}$ = percent weight water
MS_B = weight of sieve before heating
MS_A = weight of sieve after heating

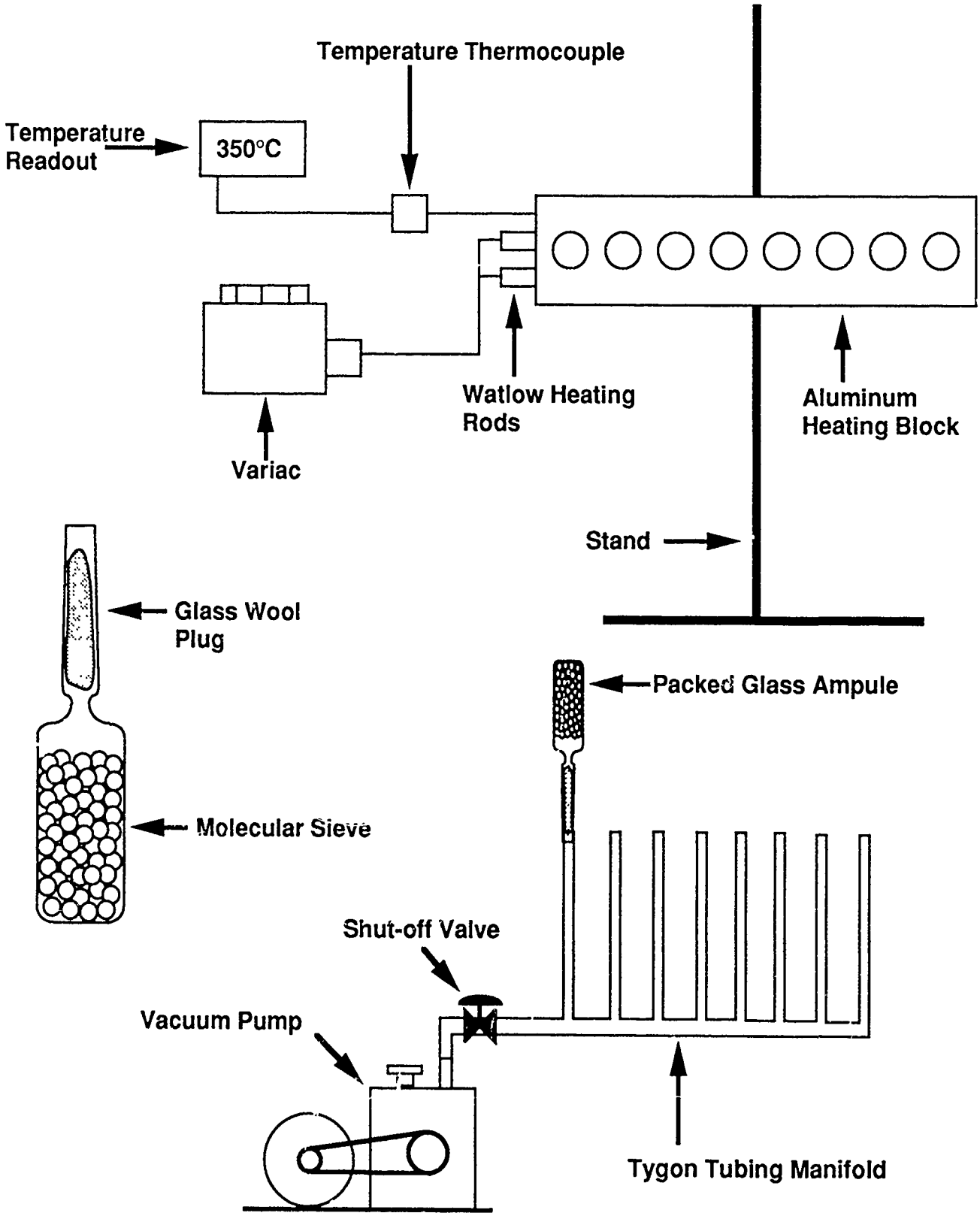

Figure 6. Gravimetric analysis apparatus.

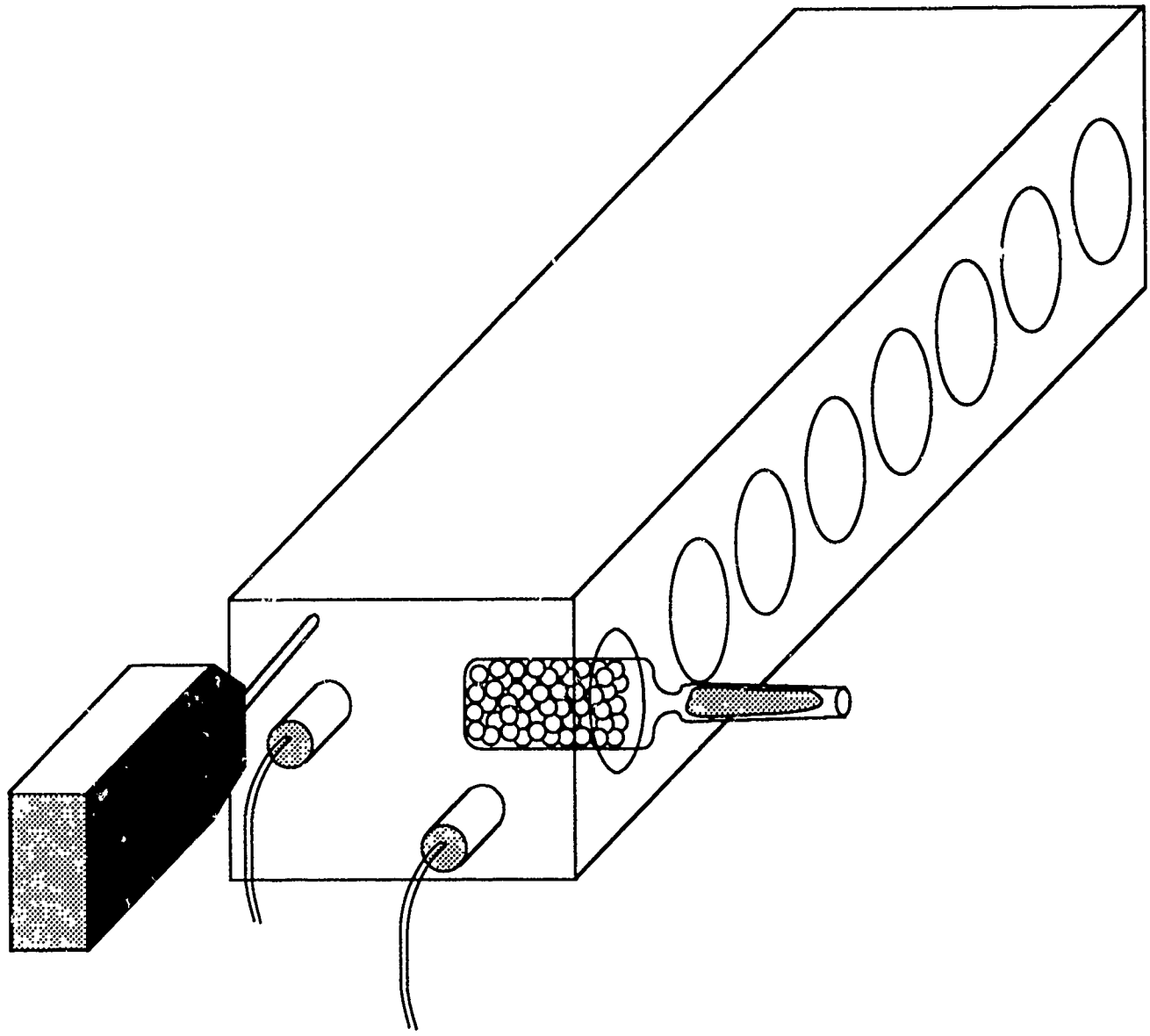

Figure 7. Detail of ampule in aluminum heating block.

APPENDIX

Activity and Washout Data for Two Sets of AV-8 OBOGS Beds

Static activity test data for NADC packed bed #1

DATE: 25-JUL-90
TIME: 09:19:05

BED IDENTIFICATION NO.:	99251-1631029-1 NADC packed bed #1
CONCENTRATOR TYPE:	CLIFTON AV-8B UNIT
TYPE OF MOLECULAR SIEVE:	U. C. 16X40 MESH 5A-MG
INPUT PARAMETERS:	
INITIAL HELIUM PRESSURE (kPa)	= 405.1 (58.7 psia)
INITIAL HELIUM TEMPERATURE (C)	= 26
FINAL HELIUM PRESSURE (kPa)	= 99.4 (14.4 psia)
FINAL HELIUM TEMPERATURE (C)	= 24
FINAL BED PRESSURE (kPa)	= 392.7 (56.9 psia)
FINAL BED TEMPERATURE (C)	= 32
WEIGHT GAIN (g)	= 67.7
RESULTS:	
BED ACTIVITY	= 83.1 %
EQUIVALENT WEIGHT % WATER	= 1.02 %

MOLECULAR SIEVE ACTIVITY IS ACCEPTABLE
EQUIVALENT WEIGHT % WATER LESS THAN OR EQUAL TO 2.5%
///// BED PASSED TEST /////

Washout data for NADC packed bed #1

Washout time for $O_2 \rightarrow N_2$ curve : 42.5 s

Washout time for $O_2 \rightarrow N_2$ curve
minus time to washout void space: 35.5 s

Static activity test data for NADC packed bed #2

DATE: 25-JUL-90
TIME: 10:15:45

BED IDENTIFICATION NO.:	99251-1631029-2 NADC packed bed #2
CONCENTRATOR TYPE:	CLIFTON AV-8B UNIT
TYPE OF MOLECULAR SIEVE:	U. C. 16X40 MESH 5A-MG
INPUT PARAMETERS:	
INITIAL HELIUM PRESSURE (kPa)	= 404.5 (58.6 psia)
INITIAL HELIUM TEMPERATURE (C)	= 27
FINAL HELIUM PRESSURE (kPa)	= 98.7 (14.3 psia)
FINAL HELIUM TEMPERATURE (C)	= 24
FINAL BED PRESSURE (kPa)	= 392.7 (56.9 psia)
FINAL BED TEMPERATURE (C)	= 32
WEIGHT GAIN (g)	= 68.0
RESULTS:	
BED ACTIVITY	= 83.5 %
EQUIVALENT WEIGHT % WATER	= 0.99 %

MOLECULAR SIEVE ACTIVITY IS ACCEPTABLE
EQUIVALENT WEIGHT % WATER LESS THAN OR EQUAL TO 2.5%
///// BED PASSED TEST /////

Washout data for NADC packed bed #2

Washout time for $O_2 \rightarrow N_2$ curve: 43 s

Washout time for $O_2 \rightarrow N_2$ curve
minus time to washout void space: 36 s

Static activity test data for LITTON packed bed #1

DATE: 12-JUL-90
TIME: 09:13:04

BED IDENTIFICATION NO.:	99251ASSY16308506 LITTON packed bed #1
CONCENTRATOR TYPE:	CLIFTON AV-8B UNIT
TYPE OF MOLECULAR SIEVE:	U. C. 16X40 MESH 5A-MG
INPUT PARAMETERS:	
INITIAL HELIUM PRESSURE (kPa)	= 405.1 (58.7 psia)
INITIAL HELIUM TEMPERATURE (C)	= 28
FINAL HELIUM PRESSURE (kPa)	= 100.8 (14.6 psia)
FINAL HELIUM TEMPERATURE (C)	= 24
FINAL BED PRESSURE (kPa)	= 397.6 (57.6 psia)
FINAL BED TEMPERATURE (C)	= 32
WEIGHT GAIN (g)	= 73.4
RESULTS:	
BED ACTIVITY	= 91.0 %
EQUIVALENT WEIGHT % WATER	= 0.49 %

MOLECULAR SIEVE ACTIVITY IS ACCEPTABLE
EQUIVALENT WEIGHT % WATER LESS THAN OR EQUAL TO 2.5%
///// BED PASSED TEST /////

Washout data for LITTON packed bed #1

Washout time for $O_2 \rightarrow N_2$ curve: 47 s

Washout time for $O_2 \rightarrow N_2$ curve
minus time to washout void space: 40 s

Static activity test data for LITTON packed bed #2

DATE: 12-JUL-90
TIME: 09:40:41

BED IDENTIFICATION NO.:	99251ASSY16308505 LITTON packed bed #2
CONCENTRATOR TYPE:	CLIFTON AV-8B UNIT
TYPE OF MOLECULAR SIEVE:	U. C. 16X40 MESH 5A-MG
INPUT PARAMETERS:	
INITIAL HELIUM PRESSURE (kPa)	= 403.8 (58.5 psia)
INITIAL HELIUM TEMPERATURE (C)	= 28
FINAL HELIUM PRESSURE (kPa)	= 99.4 (14.4 psia)
FINAL HELIUM TEMPERATURE (C)	= 23
FINAL BED PRESSURE (kPa)	= 397.6 (57.6 psia)
FINAL BED TEMPERATURE (C)	= 32
WEIGHT GAIN (g)	= 72.9
RESULTS:	
BED ACTIVITY	= 90.1 %
EQUIVALENT WEIGHT % WATER	= 0.54 %

MOLECULAR SIEVE ACTIVITY IS ACCEPTABLE
EQUIVALENT WEIGHT % WATER LESS THAN OR EQUAL TO 2.5%
///// BED PASSED TEST /////

Washout data for LITTON packed bed #2

Washout time for $O_2 \rightarrow N_2$ curve: 41 s

Washout time for $O_2 \rightarrow N_2$ curve
minus time to washout void space: 34 s

* U. S. GOVERNMENT PRINTING OFFICE: 1991--561-052/40015